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FTD-ID(RS)T-0884-77

FOREIGN TECHNOLOGY DIVISION

ON THE RELATIONSHIP BETWEEN THE LIQUID AND GASEOUS STATE IN METALS

by

Ya. Zel'dovich, L. Landau

EDITED TRANSLATION

FTD-ID(RS)T-0884-77 6 June 1977

MICROFICHE NR: FTD-77-C-000677

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By: Ya. Zel'dovich and L. Landau

English pages: 6

Source: Zhurnal Eksperimentalnoy i Teoreticheskoy Fiziki, Volume 14, Nr 1-2, 1944, PP. 32-34

Country of origin: USSR
Translated by: Robert D. Hill
Requester: ASD/ETIL
Approved for public release; distribution unlimited.

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α α *α*		Nu	Ν ν	
Beta	Β β		Xi	Ξ ξ	
Gamma	Γ γ		Omicron	Ο ο	
Delta	Δ δ		Pi	Π π	
Epsilon	Ε ε *ϵ*		Rho	Ρ ρ *ϱ*	
Zeta	Ζ ζ		Sigma	Σ σ *ς*	
Eta	Η η		Tau	Τ τ	
Theta	Θ θ *ϑ*		Upsilon	Υ υ	
Iota	Ι ι		Phi	Φ φ ϕ	
Kappa	Κ ϰ κ *ϰ*		Chi	Χ χ	
Lambda	Λ λ		Psi	Ψ ψ	
Mu	Μ μ		Omega	Ω ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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ON THE RELATIONSHIP BETWEEN THE LIQUID AND GASEOUS STATE IN METALS

Ya. Zel'dovich and L. Landau

General considerations about the nature of the transition of the substance from the state of a metal into the state of a dielectric lead to the conclusion that such a transition is completed as the usual phase transition up to a very temperature. In the case of mercury and other low-boiling metals, the critical point of the transition from the liquid to the gaseous state lies, probably, at a lower temperature. It follows to expect the existence in the defined region of two separate (at a different pressure and temperature) transitons from a metallic to a nonmetallic state and from a liquid to a gaseous state, i.e., the existence of the liquid nonmetallic phase, with an increase in the pressure of the transient into the metal and with a lowering of the pressure, into the gas.

The metal sharply differs from the dielectric with respect to its electron energy spectrum with absolute zero. The continuous spectrum of states adjoins the basic state of the metal; owing to this, as weak an electrical current as desired causes in the metal an electrical current dependent on the transition of the system to levels as close in energy to the main level as desired. Opposite to this, the electron energy spectrum of the dielectric differs by the existence of the finite "slit", a definite difference in the energies between the main state with the minimal energy (in which the current is absent) and the excited states nearest to it, in which one of the electrons of the dielectric becomes free and electrical conductivity appears.

Let us note that it is impossible to define the metal as a body with a continuum of levels adjoining the basic level without additional conditions: in actuality, any paramagnetic substance, for example, liquid oxygen or gadolinium sulfate, possesses a continuous spectrum of levels corresponding to the different values of the magnetic moment; owing to this there occurs a change in the moment in the weak magnetic field characteristic for the paramagnetic substance. However, the oxygen or gadolinium sulfate are not a metal and do not conduct current. The presence of a continuous spectrum is the condition necessary but insufficient in order that the substance would be a metal; for conductivity it is necessary that levels adjoining with the' the main excitation possess the property of transfer of the electrical charge.

The supposition that with a sufficiently powerful comprssion any substance will turn into a metal was repeatedly expressed and is probable (although it was never proven in general form). An illustration is the conversion of phosphorus into a conducting modification at high pressure - the black phosphorus of Bridgeman.

At absolute zero the metal and dielectric are qualitatively different; it is always possible to determine with what precisely we are dealing with; a definite point of the transition exists.[1]

[1] At a temperature different from zero, principally in any dielectric there occurs a certain excitation, some kind of, although

The dielectric is distinguished from the metal by an energy slit in the electron spectrum. But can the width of this slit tend toward zero with an approach (from the side of the dielectric) to the point of transition to the metal? In this case we would have the transition without the latent heat, without a jump in the volume and other properties. Peyerl's pointed out that the continuous, in this sense, transition is impossible. Let us examine the excited state of the dielectric in which it conducts current. The electron abandons its place, moves in the crystalline lattice, having revealed in another place of the lattice a positive charge. At a great distance of the electron from the positive charge, it clearly undergoes Coulomb attraction, which strives to return the electron. In the Coulomb field of attraction there are always discrete levels with a negative energy corresponding to the binding of the electron; consequently, always the excited and conducting state of the dielectric are separated by a slit of finite width from the basic state in which the electrons are connected.

If at 0°K the conversion of the metal into a dielectric is a phase transition of the first kind (i.e., with the latent heat of the transiton and jump of the properties), then it is obvious that the conversion will occur as a transition of the first kind at a low temperature different from 0°K. The continuous transition is possible only at a high temperature when the excitation and conductivity of the dielectric will become considerable. The energy of excitation of the order of the

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negligible, portion of the electrons is in an excited state, so that there is an electrical conductivity different from zero, and the system as a whole is in a state of the continuous spectrum. Therefore, it is possible to distinguish absolutely strictly from the metal at absolute zero temperature.

energy of ionization, i.e., of the order of several volts, in the worst case, 1 volt. Thus the lines of the thermodynamic equilibrium of the metallic and dielectric phase can be completed by the critical point only at a very high temperature - of the order of one volt, i.e., of the order of 10^4 degrees and, respectively, at enormous pressure. Here at the high temperature both phases are noncrystalline (the melting of the metal absolutely does not deprive it of metallic properties). The question appears about the relationship between the line of the transition from the metallic state into the dielectric state and the line of the transition liquid-gas in the case of metals/ It is absolutely clear that at low pressure the substance at low density (in the limit - ideal gas) is a nonconductor and nonmetal. In the case of mercury the energy spectrum of the gas is discrete, and in the case of paramagnetic vapors of sodium we have a continuum, which, however (as in the example of oxygen), has no direct relation to the metallicity and conductivity.

Three cases are fundamentally possible.[2] The transition from the metallic into the dielectric state is always accompanied by the transition from the liquid state into the gaseous; there is one common curve and one critical point reacheable at a very high temperature. This case, perhaps, takes place for the nonvolatile metals. For metals with a low heat of evaporation (for example, mercury), it follows to expect the critical point of the liquid-gas (point ЖГ) at a temperature much lower than the criticla point of the metal-dielectric transition (point МД).

[2] We do not examine the crystalline phases which exist at low temperatures. The appropriate transitions do not have relationships to our subject.

Here the second and third cases appear (Fig. 1 and 2).

In the second case the heating of the liquid metal at high pressure causes a jump in the density on the line Т-ЖТ; however, the phase of the lower density is also the metal ("metallic gas"). The transition to the standard gas occurs on the line Т-МД. This case is very improbable. In the third case we expect in the defined interval of pressures with an increase in temperature conversions of the liquid metal into the liquid nonconducting phase (on the line Т-МД) and only after this, on the line Т-ЖГ, conversions of the nonconducting phase into gas. Losses of the metallicity occurs by means of the phase transition of metal-gas at a temperature and pressure much higher than that which corresponds to the critical point liquid-gas.

In both last cases the appearance of the triple point T of co-existence is characteristic: in the second case - two metallic and one dielectric phase, and in the third - the metal and two dielectric (liquid and gas) phases.

In the case of mercury the comparatively low heat of evaporation indicates the fact that the point ЖГ is located closely, at 1000-1500° K according to various estimates, whereas the point МД, probably, is not at all accessible at present to experimental investigation. From our considerations it follows that in this case, apparently, the last case is exactly accomplished. The physical predictions are reduced thus: 1) to the existence of a nonconducting liquid phase and 2) to the fact that at a temperature and pressure higher than the critical there should take place a phase transition with an intermittent change in the electroconductivity of the volume and other properties.

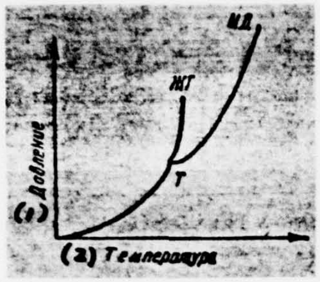

Fig. 1. KEY: 1) Pressure; 2) Temperature.

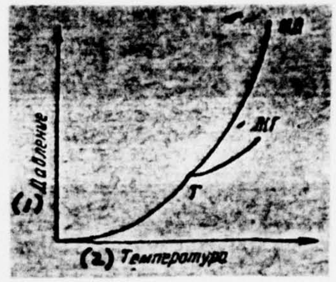

Fig. 2. KEY: 1) Pressure; 2) Temperature.

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Submitted 15 June 1943

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1. REPORT NUMBER FTD-ID(RS)T-0884-77	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ON THE RELATIONSHIP BETWEEN THE LIQUID AND GASEOUS STATE IN METALS		5. TYPE OF REPORT & PERIOD COVERED Translation
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ya. Zel'dovich and L. Landau		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Foreign Technology Division Air Force Systems Command U. S. Air Force		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 1944
		13. NUMBER OF PAGES 6
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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